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Michael L. Murphy, Charles P. Hawkins, and N.H. Anderson

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Oregon State University
Corvallis, Oregon 97333

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Effects of Canopy Modification and Accumulated Sediment on Stream Communities

MICHAEL L. MURPHY,[1] CHARLES P. HAWKINS, AND N. H. ANDERSON

Department of Entomology, Oregon State University
Corvallis, Oregon 97331

Abstract

Small streams differing in sediment composition were compared in logged and forested reaches to determine effects of accumulated fine sediment on stream communities under different trophic conditions. Three stages of forest community succession were studied in the Cascade Mountains: recently clear-cut areas without forest canopy (5–10 years after logging); second-growth forest with deciduous canopy (30–40 years after logging); and old-growth coniferous forest (>450 years old). One stream with mostly coarse sediment (56–76% cobble) and one with more fine sediment (5–14% sand and 23–53% gravel) were contrasted for each successional stage. In general, streams traversing open clear-cuts had greater rates of microbial respiration, and greater densities or biomasses of aufwuchs, benthos, drift, salamanders, and trout than did the shaded, forested sites regardless of sediment composition. We conclude that for these small Cascade Range streams, changes in trophic status and increased primary productivity resulting from shade removal may mask or override effects of sedimentation.

Fine inorganic sediment as a nonpoint-source pollutant of streams is a major concern to resource managers. Sediment occurs naturally in streams, but some land-use practices increase sediment loads of streams to the point of degrading aquatic resources (Cordone and Kelly 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). It often is difficult to assess effects of sedimentation, however, because of the inherent large natural variation in stream characteristics and because watershed practices often have multiple effects on stream ecosystems. The purpose of this study was to evaluate the role of trophic characteristics of stream systems in modifying effects of sedimentation on the stream community.

The relative importance of allochthonous and autochthonous energy sources is one of the primary determinants of structure and function of stream communities (Cummins 1974). To a large degree, availability of different energy sources is controlled by forest canopy. The food base of shaded streams is dominated by allochthonous organic matter from leaf fall, whereas in open streams the dominant food source arises from autochthonous production of periphyton. Amounts of these inputs influence the kinds of functional groups (for example leaf shredders, aufwuchs scrapers, fine-particle collectors) that can develop in a stream (Cummins 1974).

Earlier work has shown that both fauna and flora often are more abundant in sections of streams with open canopies than in forested sections (Hughs 1966; Thorup 1966; Albrecht 1968; Lyford and Gregory 1975; Aho 1976; Erman et al. 1977; Hunt 1978; Gregory 1980; Newbold et al. 1980; Murphy and Hall 1981). Removal of streamside vegetation during log-

[1] Present address: National Marine Fisheries Service, Auk Bay Laboratory, Auk Bay, Alaska 99825.

ging appears to increase aquatic production at all trophic levels by increasing periphyton production (Gregory 1980; Murphy and Hall 1981). On the other hand, many reports of logging impacts emphasize the destructive potential of accumulated sediment that adversely affects stream habitat (Cordone and Kelly 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). Thus, logging may have two opposing effects, canopy removal tending to increase stream productivity and sedimentation tending to degrade physical habitat. Is the increased aquatic production observed in clear-cut areas a general phenomenon, or it is restricted to watersheds where sediment is not a problem? Resource managers need a better understanding of the roles and relative importance of sedimentation and trophic status in the overall response of stream ecosystems to watershed practices.

This study was an attempt to resolve some of these contradictory results by focusing on the positive stimulus of canopy removal that might offset detrimental effects of sedimentation associated with clear-cut logging in the western Cascade Range of Oregon. We compared streams within logged and forested sections of watersheds in the Oregon Cascades. We sampled sediment, organic detritus, algae, insects, and vertebrates. We show that for small Cascade Range streams, changes in energy flow resulting from shade removal may mask or override effects of sediment pollution.

Methods

The study area was located in the upper McKenzie River drainage of the heavily forested western Cascade Mountains (Fig. 1). Sites were located on the Little Butte and Sardine volcanic series that are a mosaic of tuffs, breccias, and basalt of varying resistance to weathering (Beaulieu 1971). Clear-cut logging is common in the area. Typically, all trees are removed and slash is burned, usually without streamside buffer strips.

We selected streams that provided a contrast in size of streambed sediments. Three pairs of sites, each pair at a different stage of forest community succession, were sampled: recently clear-cut areas without forest canopy (5–10 years after logging); second-growth forest with deciduous canopy of *Alnus rubra* (30–40 years after logging); and old-growth coniferous forest of *Pseudotsuga menziesii* and *Tsuga heterophila*

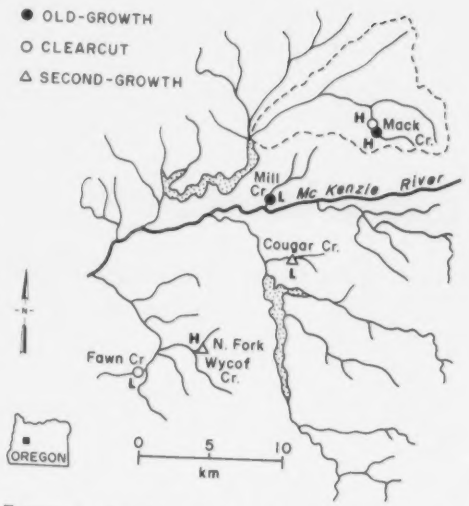

FIGURE 1.—*Locations of the study sites in the Cascade Mountains. The H. J. Andrews Experimental Forest is outlined. Stippled areas are reservoirs. H and L indicate high- and low-gradient sites, respectively.*

(>450 years). Each pair within a successional stage had a stream with relatively coarse sediment and one with more fine sediment in the stream channel. On first inspection, streambed sediment composition in the study area appeared to be closely correlated with channel gradient. Thus, sections were selected that had a channel gradient of about 10% to provide sites with relatively coarse streambeds, and that had a gradient of about 1% to provide sites with more fine sediment.

All sites were on small perennial streams of 4–8-km^2 drainage areas and minimum discharges of 0.02–0.09 m^3/second (Table 1). Maximum stream temperature was less than 21 C in all sites and was correlated with canopy density in that the clear-cut sites had the highest summer temperatures. Streams at the lower elevations with southerly aspect were slightly warmer than other streams with similar canopy density.

The high-gradient old-growth and clear-cut sites were on Mack Creek in the H. J. Andrews Experimental Forest. This watershed is about 90% undisturbed old-growth forest upstream of the sites. The clear-cut site was located 200 m downstream from the old-growth forest and was relatively undisturbed except for canopy

TABLE 1.—*Physical characteristics of the recent [illegible] (CC), second-growth (SG), and old-growth (OG) study sites along Cascade Mountain streams.*

	High-gradient streams (10%)			Low-gradient streams (1%)		
	CC	SG	OG	CC	SG	OG
Riparian age (years)	10	35	450	7	35	450
Watershed area (km²)	5.5	4.0	5.4	6.8	8.2	6.4
Percentage of watershed logged	10	32	10	36	70	65
Canopy density (%)	0	85	75	0	85	75
Discharge (minimum m³/second)	0.07	0.03	0.07	0.06	0.09	0.02
Temperature (maximum C)	18.5	15.5	15.5	20.0	14.0	18.0
Elevation (m)	730	500	760	500	500	360
Aspect	E	S	E	W	E	S

removal. The high-gradient second-growth site was on North Fork Wycof Creek. Fire burned much of the upper area of the watershed in the 1920's and about 32% of the watershed was logged in the 1940's. No new logging activity has occurred in the past 35 years. The low-gradient old-growth site was on Mill Creek, which contained about 35% old-growth forest with only a small area (8%) logged in the 1970's. The low-gradient second-growth site was on Cougar Creek. Approximately 30% of this watershed was old-growth forest. No clear-cutting was done during the 1970's. The low-gradient clear-cut site, Fawn Creek, appeared to be the most heavily disturbed of the study sites. In the 5 years preceding this study, 36% of the watershed was clear-cut. Slope failures and sluiced tributary channels contributed massive quantities of sediment to the main channel in 1977–1978.

For each site we measured angular canopy density (an index of shading) with a densiometer (see Brown 1969). The densiometer consisted of a convex mirror divided into grids and allowed a visual estimate of the percent of streambed shaded by surrounding vegetation. Stream discharge was determined during summer low flow by measuring cross-sectional area and current velocity. Stream temperature was measured with maximum-minimum thermometers from June to November 1978.

Six core samples, three in pools and three in riffles, were taken at each site during August to sample sediment and detritus. A metal cylinder (0.25 m²) was driven into the stream bottom and a constant volume of sediment (12 liters) was removed. Particles larger than 0.05 mm were sieved in the field into four size classes: sand (0.05–1.0 mm); gravel (1.0–16.0 mm); pebbles (16–50 mm); and cobbles (>50 mm). Fine silt (<0.05 mm) and water that passed through the sieves were retained in a bucket. Two subsamples (1%) of this suspension were filtered (0.45 μm pore size), dried, weighed, and burned (500 C, 12 hours) in a furnace to determine amounts of inorganic and organic matter. Density of dried silt was measured to convert weight data to volume. Volumes of sand and gravel fractions were measured in the field by water displacement, then the materials were dried and burned in the laboratory to determine inorganic and organic portions. For pebble and cobble fractions, organic matter was decanted or picked from the inorganic material, volume of inorganic sediment was measured by water displacement, and the organic portion was dried and weighed. Because silt never accounted for more than 0.2% by volume of the total sediment sample, we combined data for silt and sand in the data analyses.

Microbial respiration associated with organic detritus was measured monthly from June to September. Sediment was randomly scooped from a pool at each site and sieved into two fractions, 0.45–50.0 μm and 0.05–1.0 mm. We measured respiration on both fractions in a Gilson Respirometer (Gilson 1963), adjusting temperature of the respirometer to approximate ambient stream temperature for the sample period. Samples were dried, weighed, and ashed, and respiration ($\mu l\ O_2 \cdot hour^{-1}$) was expressed per AFDW (ash-free dry weight).

Standing crop of aufwuchs (periphyton, bacteria, fungi, and associated organic matter on rock surfaces) was estimated monthly from July to October. We used a wire brush to scrape adhering matter from three cobbles from both pools and riffles from each site each month. Scrapings were collected, dried, weighed, and

ashed. We measured the three longest orthogonal axes of each rock and calculated approximate total surface area by the formula for a rectangular solid. Aufwuchs AFDW on each rock was expressed per unit surface area of the cobble.

Benthic invertebrates were sampled during June, August, and October. We took three samples (0.1 m^2) in both pools and riffles using a modified Surber sampler (Erman et al. 1977). Organisms retained by a 1-mm mesh were counted and their lengths measured. Biomass (dry weight) was estimated from length-weight relationships. A detailed analysis of invertebrate communities will be the subject of a forthcoming paper so only major trends in density and biomass are discussed here.

Drifting invertebrates in each stream were sampled five times from June to November. A single net (opening 23 cm by 18 cm, net 1 m long, mesh 330 μm) was placed in a riffle at each site and removed 24 hours later. Drift samples were sieved into two fractions (>1.0 mm and <1.0 mm). Three subsamples (2%) of the finer fraction and all of the coarser fraction were examined under a microscope to count invertebrates. Density (number·m^{-3}) of drifting invertebrates was calculated based on the volume of water filtered.

Biomass of all aquatic vertebrates at each site was estimated by the removal method (Zippin 1956) three times at bimonthly intervals from June through October. Vertebrates in a 30-m reach of each site were collected with an electroshocker, anesthetized, identified, measured, weighed, and released within the site. Production of young-of-the-year trout (age 0+) was estimated by the instantaneous-growth method (Chapman 1971). Based on length measurements, older trout (age 1+) were difficult to separate into age-classes, and thus their production could not be accurately estimated. Scale samples were not taken. Salamanders and frogs seemed sensitive to electroshocking, and populations declined through the study period. Hence we estimated population densities and biomasses of amphibians only for the first sampling period and made no estimate of production.

Results

Sediment in the high-gradient streams consisted mostly of loose cobble and almost nothing

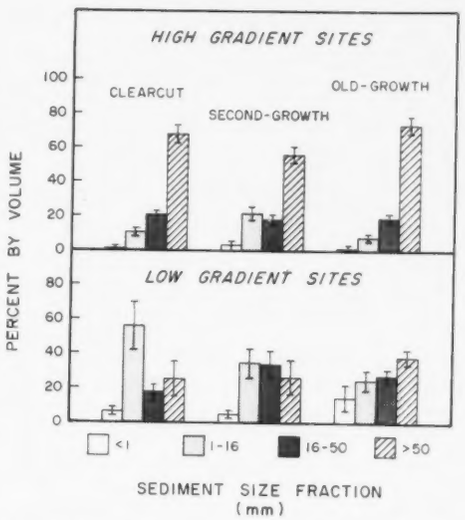

FIGURE 2.—*Size composition of inorganic sediment in cores taken from the old-growth, clear-cut, and second-growth sites (mean ± SE; N = 6).*

was finer than 1 mm. The low-gradient streams contained 36–58% sand and gravel, which embedded larger rocks, compared to 9–25% sand and gravel in the high-gradient streams (Fig. 2). The difference between high- and low-gradient sites was significant for both sand (t-test, $P < 0.01$) and gravel ($P < 0.001$).

The amount of organic matter in the streambed corresponded to channel gradient and not to forest successional stage. The low-gradient sites contained more organic detritus than did the high-gradient sites (Fig. 3): an average of 274 ± 138 (±2 SE) g·m^{-2} versus 115 ± 48 g·m^{-2} (t-test, $P < 0.025$). We found significant differences ($P < 0.01$) between high- and low-gradient sites for the two smallest size fractions, but the coarsest fraction did not differ significantly among the sites. Comparison of means also showed no significant difference between open and forested sites for any size fraction of organic detritus.

Amounts of sand and organic detritus were directly related. For individual samples, the correlation between amount of organic matter and percentage of sand was significant for all three size fractions of organic matter. The correlation was stronger for the 0.05–1.0-mm fraction ($r = 0.97$, $N = 36$) than for the 0.45–50.0-

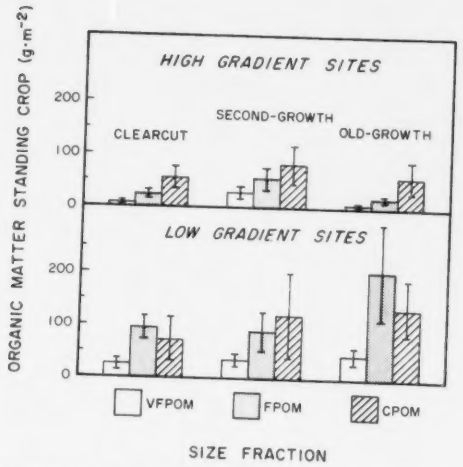

FIGURE 3.—*Amount of organic matter by size fraction in streambed sediment cores (mean ± SE; N = 6). Very fine particulate organic matter (VFPOM) = 0.45–50 μm; fine particulate organic matter (FPOM) = 0.05–1 mm; coarse particulate organic matter (CPOM) = 1–16 mm.*

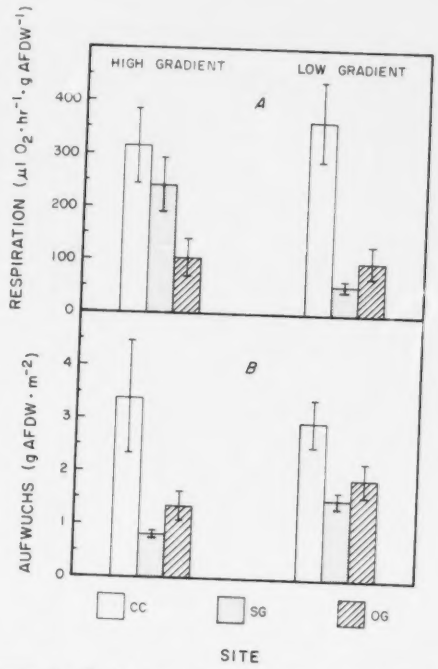

FIGURE 4.—*Respiration of organic matter taken from streambeds of the study sites (A) and standing crop of aufwuchs on rock surfaces (B). Data are mean ± SE; N = 8 measurements of respiration; N = 24 aufwuchs samples. CC = clear-cut, SG = second-growth, and OG = old-growth sites; AFDW = ash-free dry weight.*

μm fraction ($r = 0.68$) or the >1-mm fraction ($r = 0.59$).

Respiration associated with organic matter from the clear-cut sites was nearly three times greater than that from the forested sites (Fig. 4). Comparison of means showed an average 340 ± 101 μl $O_2 \cdot hour^{-1} \cdot g^{-1}$ in the clear-cut sites compared with 134 ± 44 μl $O_2 \cdot hour^{-1} \cdot g^{-1}$ in the forested sites (t-test, $P < 0.001$). Respiration did not differ significantly between old-growth and second-growth sites. We also found no consistent relationship between detrital respiration and percentage of sand in the streambed.

Clear-cut sites contained about twice as much aufwuchs as did forested sites (Fig. 4), averaging 3.1 ± 1.2 $g \cdot m^{-2}$ compared to 1.4 ± 0.2 $g \cdot m^{-2}$ in forested sites (t-test, $P < 0.001$). Aufwuchs standing crop did not differ significantly between old-growth and second-growth sites. No consistent relationship was found between standing crop of aufwuchs and percentage of fine sand. Periphyton consisted mostly of encrusted diatoms in shaded sites, whereas filamentous and other macro-algae were seasonally abundant in open sites.

Density of benthic invertebrates in the clear-cut sites averaged 1.5 and 2.3 times greater than in the forested sites during June and August, respectively (t-test, $P < 0.005$, Fig. 5). Benthic density in October, however, did not differ significantly among successional stages. In October, following leaf fall and a reduction in shading, all forested sites showed peaks in density of benthos. The increase was especially pronounced in the second-growth sites, which had mostly deciduous canopies. During October, the increased density of benthos in sites with deciduous canopies may have resulted from greater abundance of food sources due to both increased primary production and the large influx of leaves. We found no significant relationship between mean density of benthos and average sediment composition.

Biomass of invertebrates did not always parallel observed trends in density. Biomass in low-gradient sites often was dominated by the large snail *Juga plicifera*, which was very abundant in

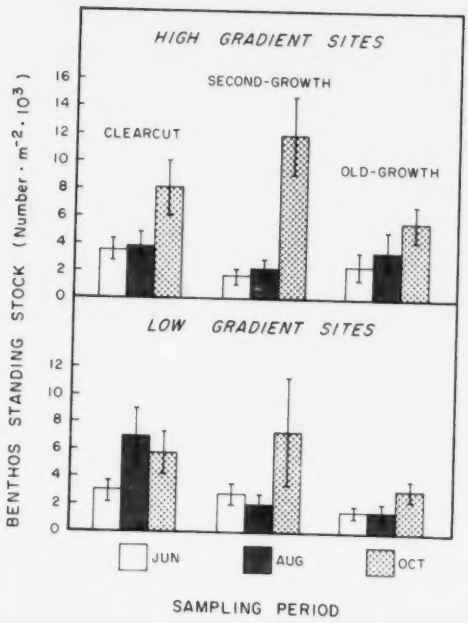

FIGURE 5.—*Density of invertebrates in benthic samples by sampling period (mean ± SE; N = 6).*

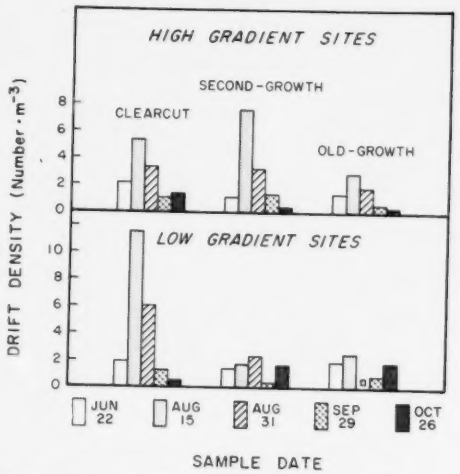

FIGURE 6.—*Density of invertebrates in 24-hour drift samples by sampling period. [a]Lost sample.*

pools. Open sites and high-gradient sites had few snails. Among riffle samples, biomass was about 2.3 times greater in open sites than in shaded streams ($P < 0.005$). However, shaded pools had 2.2 times more biomass than pools in open sections of streams, although this difference was not statistically significant. There was no difference in biomass between riffles of low- and high-gradient streams. Among pools, however, low-gradient streams had 3.4 times the biomass of high-gradient streams ($P < 0.06$).

Density of drifting invertebrates varied according to sampling date and successional stage (Fig. 6). Two-way analysis of variance with comparison of treatment means showed significant effects for both sample date ($P < 0.005$, F-test) and successional stage ($P < 0.025$, t-test). All sites exhibited peaks in density of drift in August with minima in September and October. Differences among successional stages were most pronounced during August. The maximum values for the two August sampling periods were both recorded in the low-gradient clear-cut site. Overall, the two clear-cut sites averaged 1.5 ± 1.3 individuals/m³ more than did the forested sites. We found no consistent difference in density of drift between high- and low-gradient sites.

Only five species of aquatic vertebrates were collected and no consistent difference in number or relative dominance of species was found among successional stages or between low- and high-gradient sites (Fig. 7). Dominant species were neotenic Pacific giant salamander *Dicamptodon ensatus*, cutthroat trout *Salmo clarki*, and rainbow trout *S. gairdneri*. The tailed frog *Ascaphus truei* and the reticulate sculpin *Cottus perplexus* were present in some of the sites. Effects of shade and sediment on vertebrates depended on the species (Fig. 7). Salamanders were more abundant in high-gradient sites than in low-gradient sites (paired t-test, $P < 0.025$). Biomass in the low-gradient sites averaged only 55% of that in the high-gradient sites. Salamander biomass also was inversely related to the percentage of sand in the streambed ($r = -0.90$, $N = 6$, $P < 0.05$), but biomass was not significantly correlated with amount of shade ($r = -0.48$).

Trout were more abundant in clear-cut sites than in forested sites (Table 2). Biomass was significantly greater in clear-cut than in forested sites for all sampling periods except August, when freshets reduced sampling efficiency (t-test; $P < 0.025$, < 0.25, < 0.0025 for July, August, and October, respectively). For the three sampling periods, trout biomass averaged

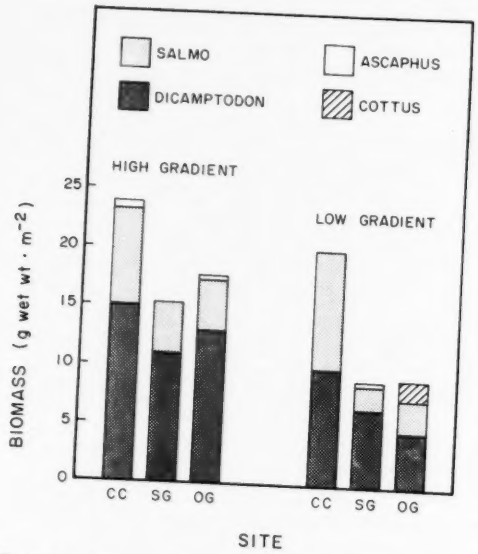

FIGURE 7.—*Biomass of stream vertebrates during summer, with amounts of salamander* Dicamptodon ensatus, *trout* Salmo *spp., reticulate sculpin* Cottus perplexus, *and frog* Ascaphus truei *indicated for each site. CC = clear-cut, SG = second-growth, and OG = old-growth sites.*

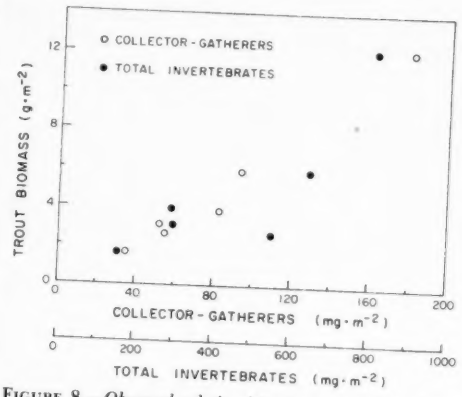

FIGURE 8.—*Observed relationships between trout biomass and riffle invertebrate standing crops. Values for both trout and invertebrates are means of 3 months (June, August, and October) for each site (r = 0.99, P < 0.01 for trout versus collector-gatherers; r = 0.83, P < 0.05 for trout versus total invertebrates).*

about three times more in the clear-cut sites than in the forested sites, with a mean of 9.0 ± 4.4 $g \cdot m^{-2}$ in the clear-cut sites compared with 2.9 ± 0.7 $g \cdot m^{-2}$ in the forested sites. Average trout biomass (June–October) was strongly correlated with mean monthly biomass of collector-gatherer invertebrates (see Merritt and Cummins 1978) and moderately correlated with total invertebrate biomass from riffle samples (Fig. 8). Correlations between trout biomass and both mean density of collector-gatherers and mean density of total invertebrates from riffles were also significant ($r = 0.88$ and 0.89, respectively; $N = 6$; $P < 0.01$). We found no consistent relationship between trout biomass and percentage of sand in the streambed. Mean weight of age-1+ trout also did not differ significantly between high- and low-gradient sites nor among successional stages (Table 2).

Young-of-the-year (age-0+) trout constituted only 0–26% of total trout biomass because of their small size (Tables 2 and 3). Density and biomass of age-0+ trout in October, when their biomass was greatest, was significantly greater in the clear-cut sites than in the forested sites (*t*-test, $P < 0.05$). Growth and production were measured for two periods, July–August and September–October (Table 3). Growth rate was directly related to the average amount of insect drift during the corresponding period ($r = 0.76$; $P < 0.05$; $N = 8$; sites and periods with densities $<0.05 \cdot m^{-2}$ of age-0+ trout excluded). Production through the study period was significantly greater in the clear-cut sites than in the forested sites (*t*-test, $P < 0.05$) and was particularly high in the low-gradient clear-cut site.

TABLE 2.—*Trout standing stock ($g \cdot m^{-2}$) by site and sampling period and mean weight (g) of age-1+ individuals in Cascade Mountain streams. Values are wet weights. CC = clear-cut, SG = second-growth, and OG = old-growth sites.*

Sampling period	High-gradient streams			Low-gradient streams		
	CC	SG	OG	CC	SG	OG
			Standing stock			
Jun	8.3	4.5	4.2	10.0	1.9	2.7
Aug	2.4	4.9	1.9	7.7	1.4	1.9
Oct	7.0	2.1	3.2	18.7	1.5	3.1
Mean	5.9	3.8	3.1	12.1	1.6	2.6
			Mean weight of age-1+ trout			
Jun	22.4	29.9	15.0	18.0	11.1	16.8
Aug	18.5	15.5	17.0	18.5	10.6	16.8
Oct	21.4	18.6	18.5	17.8	13.7	16.8
Mean	20.8	24.7	16.8	18.1	11.8	16.8

TABLE 3.—*Standing stock ($g \cdot m^{-2}$), instantaneous growth rate (G), and production ($mg \cdot m^{-2} \cdot day^{-1}$) of age-0+ trout by site and sampling period. CC = clear-cut, SG = second-growth, and OG = old-growth sites.*

Sampling period	High-gradient streams			Low-gradient streams		
	CC	SG	OG	CC	SG	OG
			Standing stock			
Jul	0.4	0.0	[a]	2.0	0.1	0.5
Aug	0.3	0.0	0.1	1.2	0.2	0.2
Oct	1.0	0.0	0.2	4.9	0.1	0.4
			Growth rate			
Jul–Aug	0.0090	−0.0018	[a]	0.0136	0.0026	0.0027
Sep–Oct	0.0065	[b]	0.0081	0.0015	0.0007	0.0096
			Production			
Jul–Aug	3.6	0.0	[a]	21.5	0.4	1.0
Sep–Oct	4.2	0.0	1.0	4.5	0.1	3.3

[a] Fry not completely emerged.
[b] No age-0+ trout present.

Total biomass of aquatic vertebrates during July was about 1.5 times greater in the clear-cut sites than in the forested sites, averaging 22.0 ± 4.3 $g \cdot m^{-2}$ in the clear-cut sites compared to 12.8 ± 4.3 $g \cdot m^{-2}$ in the forested sites (Fig. 7). Total density in the clear-cut sites was about double that in the forested sites, with an average of 2.6 ± 0.1 individuals $\cdot m^{-2}$ in the clear-cut sites compared with 1.3 ± 0.5 in the forested sites. The difference between clear-cut and forested sites was significant for both total biomass (t-test, $P < 0.05$) and total density ($P < 0.025$). We found no consistent difference in biomass or density between second-growth and old-growth sites.

Discussion

Two major patterns emerge from the data: (1) streams in open clear-cut sites had higher microbial respiration associated with organic matter; greater standing crops of aufwuchs, benthic invertebrates, trout, and other vertebrates (all species combined); greater density of drifting invertebrates; and greater production of trout than did the shaded old-growth and second-growth sites; (2) low-gradient streams contained more fine sediment and organic matter and less salamander biomass than did the high-gradient streams. Our data corroborate studies by Albrecht (1968), Erman et al. (1977), Hunt (1978), and Murphy and Hall (1981) that showed greater abundance of aquatic species in clear-cut or open sections of streams than in shaded stream sections. In addition, our data indicate that strong linkages exist between light levels reaching the stream, primary production, microbial respiration, invertebrate production, and ultimately vertebrate production.

Periphyton production in small streams in the study area is light-limited (Gregory 1980). Chapman and Knudsen (1980) use similar arguments to suggest that fish production in some streams of the Pacific northwest is indirectly light-limited. Increased amounts of periphyton in clear-cut zones become available to other trophic levels both as live algae and as organic detritus. Because of its low C/N ratio, periphyton may be a higher quality food than allochthonous organic matter (Boyd 1973; Anderson and Cummins 1979). Microbial respiration in clear-cut sites was relatively high probably because of live algae associated with detritus and because dead algae enriched the organic detritus in the streambed providing a higher quality substrate for microbes.

Few detrimental effects of fine sediment were observed, perhaps because levels of accumulated fine sediment in the study streams were below thresholds that are detrimental to the stream community. Generally, sediments 0.1–3.3 mm have the most disruptive effects on stream communities and fish spawning habitat (Iwamoto et al. 1978). In our study, sediment less than 1 mm never accounted for more than 14% of the streambed, a level that did not appear to adversely affect the community. Except for the abundance of the salamander (*D. ensatus*), which was inversely related to the amount of accumulated sand, most other components of the stream community varied according to

the amount of shade over the stream regardless of sediment composition.

Sediment load and canopy removal, however, both may have adverse effects in some situations not encountered in this study. Increases in sediment load may cause the stream to become wide and shallow, often with a braided channel (Leopold et al. 1964). Filling of pools with sediment may reduce suitable habitat for trout (Bjornn et al. 1974). This was not observed in our sites where large woody debris from logging and natural blowdown created a stairstep channel profile and formed plunge pools downstream of debris accumulations (see Keller and Swanson 1979). Canopy removal may cause increases in stream temperature that can be lethal to trout (Moring and Lantz 1975). Stream temperature did not exceed 21 C in our sites, but temperature may be an important limiting factor for salmonids in smaller or shallower streams (Brown 1974) or in warmer climates.

Small Cascade Range streams generally have a high capacity to flush introduced sediment downstream because of their steep gradient. Even with the relatively massive inputs of sediment in Fawn Creek, the low-gradient clear-cut site, most sediment less than 1 mm apparently was removed from the surface layers of the streambed within 1 to 2 years. Fawn Creek showed large accumulations of gravel (1–16 mm), and accumulated gravel was still apparent in the second-growth sites 30 years after logging. However, instead of adversely affecting fish production, accumulated gravel may have acted to enhance production by supplying optimal substrate for retention of detritus and habitat for some species of invertebrates (see Rabeni and Minshall 1977; Williams 1978).

Streams of the Cascades are sediment-poor compared to those in other geologic provinces. Mean annual yield of suspended sediment from an undisturbed forested watershed in the western Cascades was only 13 $t \cdot km^{-2}$ (1960–1968) and from a clear-cut watershed it was 68 $t \cdot km^{-2}$ (1963–1968, Fredricksen 1970). In comparison, three Coast Range streams in Oregon averaged 53, 97, and 102 $t \cdot km^{-2} \cdot year^{-1}$ from undisturbed forest (1959–1964), and clear-cutting one of these nearly tripled its yield (Beschta 1978). Coastal streams of California are even more erosive, annually exporting 2,000–3,000 $t \cdot km^{-2}$ (Karlin 1979). Results from the Cascades may not be applicable to other regions where effects from sedimentation may be more severe.

The effects of sedimentation in a stream, however, always should be viewed in the context of the whole drainage network. Sediment deposition depends on stream competence and capacity, which vary along the longitudinal profile of a stream (Leopold et al. 1964). Fine sediment exported from high-gradient headwater channels deposits downstream where gradient is lower. These inputs from a large number of disturbed tributaries might overload downstream reaches with sediment and reduce water quality and aquatic productivity. Although headwater channels of Cascade Range streams appear minimally affected by sediment, their resistance to sedimentation may be purchased at a cost to productivity downstream.

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